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Thermoluminescent Dosimetry for LDEF Experiment M0006

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INTRODUCTION

Experiment M0006 on the Long Duration Exposure Facility had as its objective the investigation of space radiation effects on various electronic and optical components, as well as on seed germination. It was a team effort involving the Perkin Elmer Corporation, the City University of New York, Patrick Air Force Base, the Walt Disney Epcot Center, and the Grumman Corporate Research Center (CRC). The Grumman CRC provided the radiation dosimetric measurements for M0006, comprising the preparation of TLD dosimeters and the subsequent measurement and analysis of flight exposed and control samples. In addition, various laboratory exposures of TLD's with gamma rays and protons were performed to obtain a better understanding of the flight exposures.

DOSIMETER PHYSICAL DATA AND EXPOSURE CONDITIONS

Experiment M0006 was located in Row 2 (near the trailing edge), Bay C, i.e., facing west and approximately midway between the earth end and space end. The payload was contained in a drawer located in an aluminum canister. The canister had a honeycomb milled out of the top surface to promote heat transfer, and was between 1.5 and 3 cm thick. The honeycomb surface had a sheet of aluminum attached, with thickness between .2 and .4 cm. The drawer was programmed to open 10 days after launch and remain open for 10 months before retracting into the aluminum canister. Several small craters observed on the mirror samples in the test array indicated that the drawer did open during flight. To provide for the radiation dosimetry of the payload, we prepared a set of 50 Harshaw TLD-100 dosimeters, each of dimensions 0.32 cm x .32 cm x .038 cm and nominal weight 0.01g. These dosimeters were preselected for weight uniformity, annealed to 450°C while recording their preflight luminescence response (nominally zero), and sent to Patrick AFB for LDEF deployment. However, only five dosimeters were incorporated into

M0006 and five more were retained as ground controls. The five flight samples were imbedded in 15-25g of seed in a sealed aluminum tube (7 in. long ,and 1 in. ID) with a wall thickness of 1/16 in. (.43 g/cm^2).

Predictions of the AP8/AE6 trapped particle model are that LDEF during its 2105 day mission encountered an omnidirectional proton integral fluence (E>10 MeV) of 4.5 of 10^9 cm^{-2} and an omnidirectional electron integral fluence of 5.3 x 10^{10} cm^{-2} (E>0.5 MeV), as reported in Ref. 1, taking into account the decay of the orbit (from 258.5 to 172 NMi). Also, the last 27% of the mission (565 days) were spent under solar maximum conditions, during which time 15% of the proton fluence and 24% of the electron fluence were accumulated, according to the AP8/AE6 Solar Max./Solar Min. model predictions (Ref. 1). The dose at the center of a variable-radius aluminum sphere, as calculated with the SHIELDOSE code (Ref. 2) is shown in Fig. 1, displaying separately the dose contribution from protons and electrons. It is seen that while the total dose is dominated by electrons up to aluminum thicknesses of ~.1 g/cm^2, the dose for aluminum thicknesses greater than ~.5 g/cm^2 essentially is all due to protons.

The proton environment for low-earth orbits has become known not to be omnidirectional, however, but to exhibit a west (LDEF trailing edge) - east (LDEF leading edge) asymmetry. This is evidenced in dosimetry results for LDEF experiments P0006 and P0004 (trailing edge deployment) versus M0004 (leading edge), where the trailing edge (west) results, at least up to ~2 g/cm^2 of effective shielding, are about 2.5 times larger than for leading edge deployment and are reasonably well fitted by the omnidirectional trapped particle model with a spherical shield approximation (while the leading edge data appear to agree with a planar shield approximation). Since experiment M0006 was located at the trailing edge, these considerations are relevant to our dosimetry results. We also note that since the effective shielding for the M0006 dosimeters was substantially larger than .5 g/cm^2, the dose results are due to only protons, according to the model.

DOSIMETER EVALUATION RESULTS AND DISCUSSION

LDEF Flight and Control Specimens

The LDEF dosimeters were received in our laboratory in April 1990. We labeled the flight specimens with the prefix F and the ground control samples with G; the other part of the flight specimen designation refers to the seed variety whose exposure was monitored. The F samples were expected to have a variation of ~10%; multiple dosimeters at each location in the seed capsule would have reduced the variation considerably. The G (control) samples experienced a cumulative

background exposure on the ground during about 6 years, plus a dose incurred in one New York-Florida round-trip flight. We cite our measurement of a New York-Los Angeles round trip flight exposure of 20-30 mr as an upper limit to the commercial flight exposure. These control samples, because of their low-level exposure, were expected to show a much larger relative variation in reading than their flight sample counter parts.

For the dose measurements we typically heated the dosimeter samples to temperatures high enough to obtain a complete thermoluminescence release (about 400°C), recording both the total counts and the glow-curve. The glow curves in all cases were recorded as the output of a logarithmic amplifier, the ordinate thus being proportional to the logarithm of the luminescence counts per unit temperature interval. This form of data recording accentuates differences in the glow peak shapes as an aid to studying differences in exposure conditions. The calibration was based on Frick dosimetry for Co-60 exposures up to a kilorad. The results of our dose readings for both F and G sets of TLD specimens are shown in Table 1. For the flight specimens the dose measurements, accurate to within 10%, range from 180 to 244 rads (LiF), with an average of 210 rads. The control samples (G set) show a minimal exposure, averaging 0.9 rad. The large scatter in the flight sample results is remarkable, since the TLD's were deployed in close proximity (seed tube interior) under virtually identical conditions. A predominantly electron/bremsstrahlung environment would have produced a much greater exposure uniformity. The flight sample dose readings generally are comparable to the results reported for Experiment P0006: ~260 rads (tissue) or ~205 rads (LiF) at an estimated effective shield thickness of ~12.5 g/cm^2 (Ref. 3). However, our determination of effective shielding for Experiment M0006 is still pending, since the LDEF mass distribution analysis (Ref. 4) has not yet been completed; we also have the complication of an open experiment drawer for the first 10 months of the mission.

LDEF Samples ±10%		Controls	
FPINTO-1	244 rads	GPINTO-1	1.4 rads
FPINTO-2	205 rads	GPINTO-2	0.4 rads
FM-1	230 rads	GM-1	0.9 rads
FM-2	180 rads	GM-2	1.4 rads
FCORN	192 rads	GCORN	0.4 rads

Table 1. TLD Measurement Results

As part of our analysis of the flight sample glow curves, the 5 F-set TLDs upon readout and anneal were re-irradiated with Co-60 gammas to a level of ~240 rads and their glow curves remeasured. Figure 2 illustrates the measurements for sample FCORN: The upper glow curve refers to the LDEF signal (a net of 5090 counts), while the lower glow curve obtains for the subsequent gamma exposure of the same TLD (a net of 6193 counts). We note that the gamma-exposed sample has two low-temperature peaks (at 100° and 135°C for this measurement, although the exact temperature location of the glow peaks depends somewhat on the readout heating rate), which are absent for all flight-exposed samples. A third peak (at 170°C) is considerably weaker in the flight exposure. Higher-temperature peaks (at 220°C and 290°C, labeled as peaks A and B, respectively) are common to both glow curves, although the intensity ratio of the 220°C peak to 290°C peak is smaller for the LDEF exposure (~3.7) than for the re-exposure with gammas (~5.1). This difference in intensity ratios for the two peaks was observed consistently for the entire F set, as shown in Table 2. It is tempting to attribute the glow curve differences to a long-term annealing process in the flight-exposed samples. Preliminary estimates indicate that the M0006 average tray temperature remained within a range of 10-30°C (*), so that the anneal would have proceeded at room temperature. Regarding the glow curve comparison in Fig. 2, the 100° peak and 135° peaks in the re-irradiation glow curve are known to have a half-life of 10 hours and 0.5 years, respectively, so that their absence in the LDEF dose signal plausible might be due to annealing (although they also have been found absent in fresh laboratory proton exposures). Another peak at ~170° which appears as a shoulder to the 220° peak in the gamma-exposed sample and has a half-life of 7 years is also noticeable in the LDEF signal. The main peak, at 220°C, however, has an 80-year half-life and, therefore, should not have been subject to signal loss in the LDEF sample. Hence, the differences in the ratios of the A and B glow peaks between the LDEF signal and gamma reirradiation results are hard to explain by annealing considerations.

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*T. Sampair, Lockheed, Private Communication

Sample	LDEF Exposure	Fresh Gamma
FPINTO-1	3.82	5.43
FPINTO-2	3.74	4.82
FM-1	3.38	5.10
FM-2	3.58	4.63
FCORN	3.92	5.39
AVERAGE	3.69	5.07

Table 2. Ratio Peak Intensities at 220°C and at 280°C

Laboratory Proton Exposures

Prompted by the observation that the shapes of the glow curves obtained for the M0006 dosimeter flight exposures, especially the A to B peak ratios, were not reproduced in gamma ray exposures to comparable dose levels, we undertook a series of dosimeter exposures with protons, ranging in energy from 200 MeV down to 3.7 MeV. The specific purpose of this work was to determine whether proton exposures could produce a better match to the LDEF-exposed sample glow curves than the gamma exposures in emulating some of their main features. The dosimeters used in these laboratory simulations were again TLD-100 of dimensions .32 cm x .32 cm x .09 cm with a luminescence response about 2.1 times stronger than for the specimens flown on LDEF. The monoenergetic proton exposures were performed at the proton LINAC (200 and 141 MeV) and at the tandem Van de Graaff accelerator (27 and 10 MeV), both at Brookhaven National Laboratory, as well as at the Grumman Van de Graaff accelerator (3.7 MeV). Exposure levels ranged from ~200 to ~4600 Rads (LiF); for two of the bombarding energies (200 and 29 MeV) samples were exposed to two dose levels. The various irradiation conditions and the results obtained for glow peaks A and B are summarized in Table 3. As indicated earlier, peak A appears between 220 and 230°C, and peak B between 280 and 290°C. The peak data listed are proportional to the logarithm of the peak luminescence counts per unit temperature interval, with all data for the same exposure condition (energy and dose) having the same proportionality factor. The listed irradiation conditions, in addition to the bombarding energy include the average and peak values of

the ionization depth dose, as well as the energy deposition per ion, the exposure depth range, and the LET average over the exposure depth. For proton ranges less than the dosimeter thickness, the energy deposition contains the Bragg peak and the depth dose profile becomes significantly nonuniform. For example, for the 10-MeV exposure the entrance dose is 300 Rads, while the end-of-range dose is ~1.7 KRad. The dose data listed are analytical estimates, obtained with the Monte Carlo code TRIM (Ref. 5) on the basis of the measured bombarding proton fluence; for the 200- and 141-MeV exposures they are confirmed independently by carbon nuclear reaction dosimetry. The measured glow peak ratios A/B in Table 3 generally are much lower than those listed in Table 2 for laboratory gamma exposures and except for one exposure also lower than the LDEF flight sample values. There is no clear cut dependence on the proton energy, nor on the average LET value. However, where two exposure levels were produced at the same bombarding energy (200 and 29 MeV), the larger dose shows a smaller A/B peak ratio. For the 29-MeV exposure, where the 200-Rad entrance dose most closely resembles the LDEF flight exposures, the ratios of the peaks also approximate the corresponding LDEF data and also are significantly smaller than the ratio values for laboratory exposures with gammas at the same dose level. Again for the 29-MeV proton exposure an increase in the entrance dose to ~1000 Rad produces a nearly factor-of-two decline in the peak ratio. A comparable trend, although weaker, is seen for the 200-MeV exposure, where a 3.25-fold increase in the dose results in 25% decrease in the ratio. We note that for the proton measurements, reductions in the A/B peak ratio stem predominantly from a relative growth of peak B. This and other significant features of the proton glow curve structures are apparent in Fig. 3 and 4 (see footnote*), which should be compared with the glow curves given in Fig. 2. A main point in the comparison is that, just as for the LDEF flight samples, none of the proton laboratory exposures have the low-temperature glow curve structure observed for the laboratory gamma exposure (Fig.2). (Annealing considerations for the proton exposures do not apply, because of prompt readout.). This feature and the relative increase in peak B suggest a qualitative difference between the response of TLD-100 to protons (locally strongly ionizing) and to weakly ionizing radiation (gammas). The tentative conclusion, based on a limited set of laboratory simulations, is that the dose read from TLD flight samples was predominanly due to protons, in agreement with the radiation transport prediction.

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*T. Sampair, Lockheed, Private Communication

PROTON ENERGY (MEV)	ESTIM. ABSORBED DOSE (RAD(LiF)) AVG.	MAX.	ENERGY DEPOS. (MeV/Ion)	EXPOSED DEPTH (μm)	GLOW CURVE DATA FOR A & B PEAKS kxA	kxB	A/B	Avg. LET $\frac{\text{MeV cm}^2}{\text{g}}$
200	1.45×10^3	1.45×10^3	0.86	889	26.0	14.7	2.26	3.68
					27.0	15.2	2.21	
	4.56×10^3	4.56×10^3			74.8	44.2	1.69	
					73.0	44.2	1.69	
141 (200 MeV Atten. by 15.42 g/cm^{2}Al)	3.59×10^3	3.59×10^3	1.1	889	45.0	26.1	1.72	4.64
					45.8	27.0	1.67	
29	216	228	4.0	889	29.9	9.2	3.25	16.9
					28.9	7.8	3.71	
	1.08×10^3	1.14×10^3			48.6	26.5	1.83	
					44.5	22.3	2.00	
10	560	1.69×10^3	10.0	569	49.0	34.9	1.40	66.7
					27.4	19.1	1.69	
3.7	2.95×10^3	5.31×10^3	3.7	101	47.8	49.7	.96	139
					49.5	50.2	.98	

Table 3. Proton TLD Glow Curve Analysis

SUMMARY

Measurements on TLD-100 specimens flown in a seed capsule in LDEF experiment M0006 have registered exposures ranging from 180 to 244 Rads (LiF). Glow curves for the flight specimens were found to differ significantly from those obtained for gamma exposures in the laboratory at comparable dose levels. The flight samples showed a virtual absence of the low-temperature peak structure seen in the gamma exposures, and a relatively larger glow peak at 280^{o}C as compared to the main peak at 220^{o}C. A series of laboratory exposures of TLD-100 with protons from 3.7 to 200 MeV resulted in glow curves agreeing with the characteristic features of the flight samples. A tentative conclusion from this work is that the M0006 exposure was primarily due to protons, in agreement with the AP8/AE8 environment model and radiation transport analysis. The measured dose levels are consistent with an omni-directional effective shield mass of 12 g/cm^2 Al.

REFERENCES

1. J. Watts, NASA-MFSC, Geomagnetically Trapped Proton and Electron Fluences Encountered on the LDEF Mission, Presented at IRSIG Meeting, Jan. 24, 1991
2. S. M. Selzer, SHIELDOSE, IEEE Transactions on Nuclear Science, Vol. NS-26, No. 6, Dec. 1979
3. E.V. Benton et al., First LDEF Post Retrieval Symposium, June 1991
4. B.L. Colborn and T.W. Armstrong, First LDEF Post Retrieval Symposium, June 1991
5. J. F. Ziegler, J. P. Biersack, and U. Littmark, "The Stopping and Range of Ions in Solids," Pergamon Press, New York, 1985

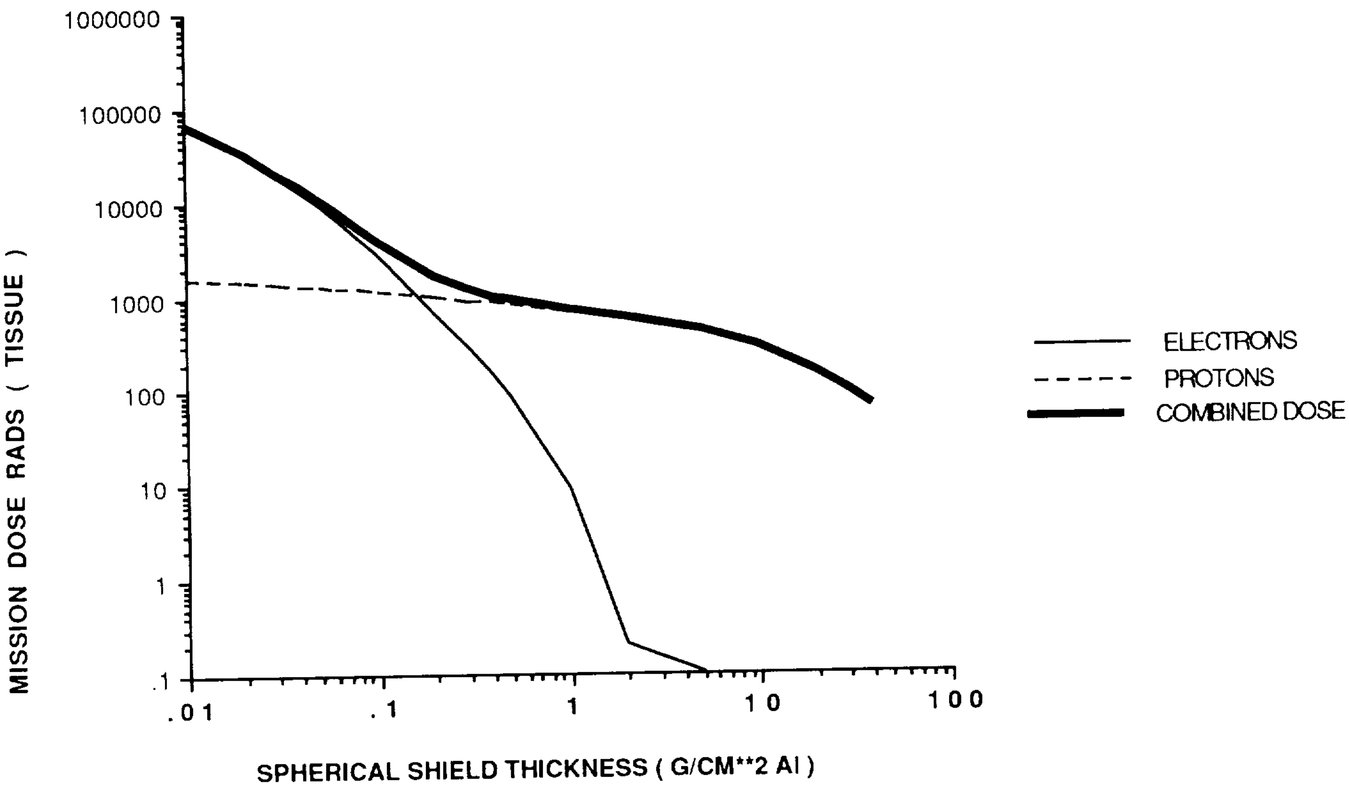

Fig. 1 LDEF Mission Dose from Trapped Radiation
(Spherical Aluminum Shield)

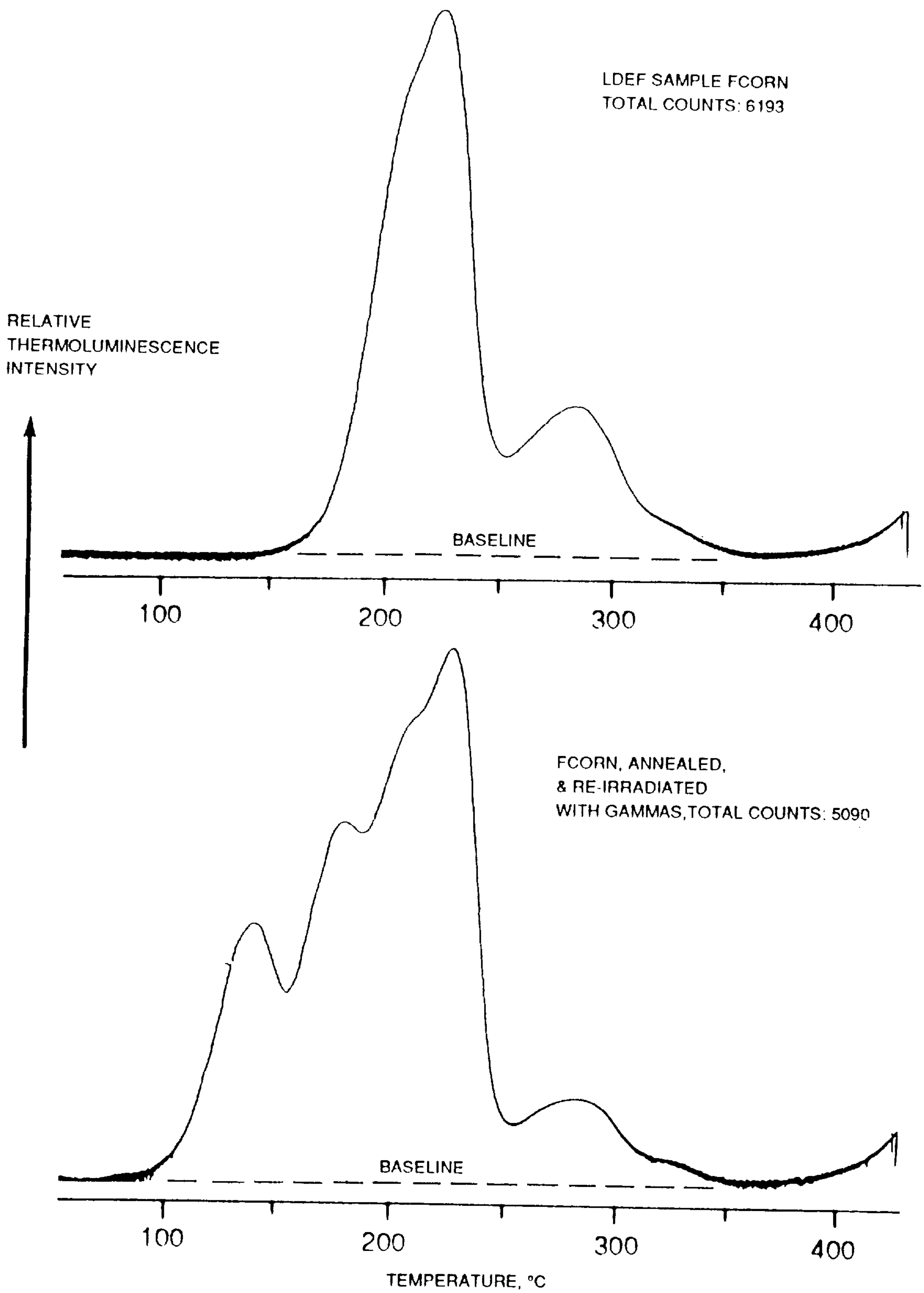

Fig. 2 Glow Curves for LDEF Sample FCORN, and for Same Sample Freshly Irradiated with Co-60 Gammas

216 RADS

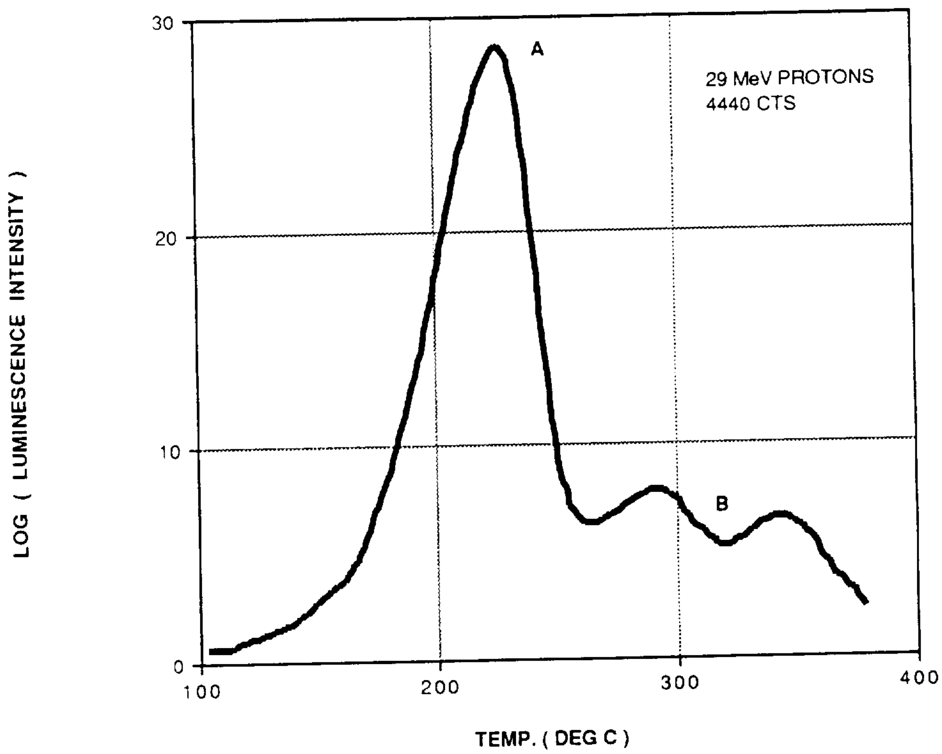

Fig. 3 Glow Curve for TLD-100 Irradiated with 29-Mev Protons to 216 Rads (LiF)

1.08 KRAD

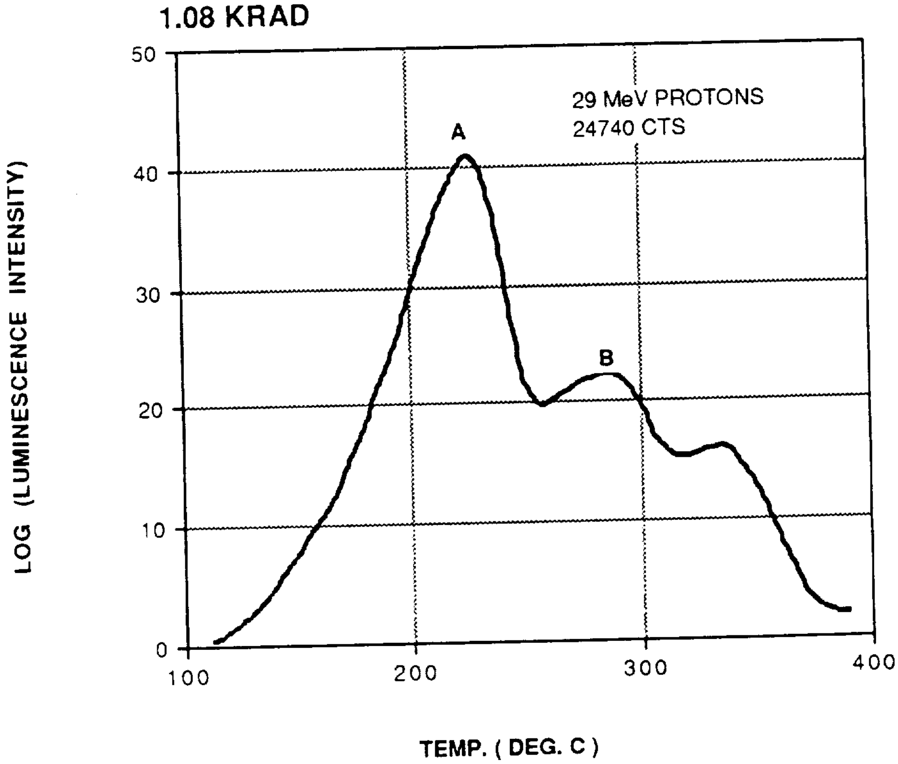

Fig. 4 Glow Curve for TLD-100 Irradiated with 29-MeV Protons to 1.08 KRad (LiF)

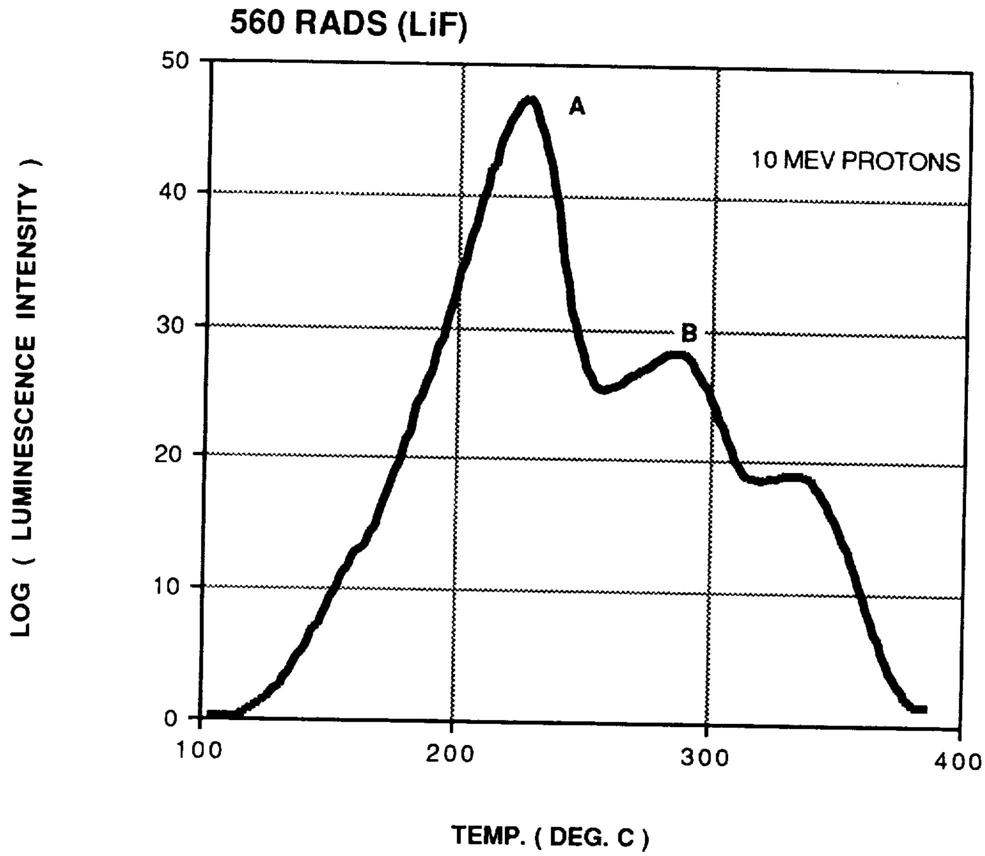

Fig. 5 Glow Curve for TLD-100 Irradiated with 10-Mev Protons to 560 Rads (LiF)